Correlation Between Flexural and Direct Stress Low-Cycle Fatigue Tests   Report 2460

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

ANNAPOLIS DIVISION - ANNAPOLIS, MARYLAND 21402

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Correlations Between Flexural and Direct Stress Low-Cycle Fatigue Tests

By

M. R. Gross and E. J. Czyryca

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MARINE ENGINEERING LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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ABSTRACT

Flexural and direct stress low-cycle fatigue results for six materials are compared. The materials are HY-100 and HY-140 steels, Monel-400, cast and wrought 70-30 cupronickel, and Ni-Al bronze. It is concluded that the two methods of test give equivalent results within the life range investigated when correlated on a total strain range basis. Correlations based on nominal stress are not as good because of differences between the cyclic stress-strain relationships for the two types of tests.

ADMINISTRATIVE INFORMATION

This investigation was conducted under Sub-project S-F020 01 01, Task 0856, Fatigue of Metals, on Assignment 86 108.

ACKNOWLEDGMENT

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INTRODUCTION

A high precentage of the fatigue data developed in laboratory tests is obtained under cyclic bending (flexural) conditions. The advantages of flexural testing lie in its simplicity and minimal equipment costs.

When MEL initiated low-cycle fatigue studies several years ago, the Lehigh-type flexural fatigue specimen was selected as being best suited for our needs. The selection was based on the following considerations:

- The rectangular shape of the specimen is more representative of shell plating than is a round-type specimen.

- High stresses and strains can be developed in flexure specimens with simple and inexpensive equipment.

- The flexure specimen is not subject to misalignment and buckling.

- Background data were available for the Lehigh specimen on boiler and pressure vessel steels.

The main objection to flexural testing is that the stress is not uniform throughout the cross section and thus is not amenable to rigorous stress analysis. Of particular concern is the finite fatigue life region wherein specimen failure may entail partial plastic deformation in the test section. Accordingly, it has been assumed by some designers that low-cycle fatigue data derived from flexure tests are of questionable value and that direct stress (axial loading) results are to be preferred, if not mandatory.

The purpose of this investigation is to compare the low-cycle fatigue results obtained from flexure tests conducted at MEL with direct stress test results obtained by NASA, Lewis Research Center, on the same materials.

MATERIALS

Six materials of interest to the Navy were selected for comparative testing. The chemical composition and mechanical properties of the materials selected are shown in the following tabulation.

METHOD OF TEST

The flexure specimen used in the MEL tests is shown in Figure 1. The short end of the specimen is held stationary while the long end is flexed between electrical or mechanical stops by a hydraulic piston. One or more strain gages (0.25-inch gage length) are attached to the minimum test section to record the longitudinal strain.

All of the flexural fatigue tests were conducted in air and were of the completely reversed type (mean deflection ≈0). The cycle rate was either 1 or 5 cpm. The specimens were cycled until stress-strain conditions stabilized (approximately 10 cycles), at which time the load versus strain diagram was recorded. The total moment range (ΔM) and total strain range ($\Delta \epsilon_t$) were obtained from these diagrams and used to calculate the nominal reversed stress and the reversed pseudoelastic stress as follows:

$$S_R = \frac{\Delta Mc}{2I} \quad \text{.....(1)}$$

where

S_R = nominal reversed stress, psi

I = moment of inertia of minimum cross section, inches to the fourth power

c = distance from neutral axis to outermost fiber at minimum cross section, in.

Chemical Composition and Mechanical Properties of Materials

Material	MEL Material Code	Condition	Chemical Composition, %												Mechanical Properties				
			C	Mn	S	P	Si	Ni	Cr	Mo	Fe	Cu	Al	Other	YS 0.2% ksi	TS ksi	ELONG in 2 in. %	RED of Area %	E x 10^6 psi*
HY-100 Steel	DQC	Q&T	0.15	0.43	0.026	0.009	0.22	2.97	1.64	0.43	Bal	-	-	-	114	127	22	70	30
HY-140 Steel	DZH	Q&T	0.10	0.73	0.005	0.005	0.28	5.00	0.57	0.53	Bal	-	-	V 0.07	147	155	20	65	30
Monel-400	DZF	HR ANN.	0.17	-	0.007	-	0.19	64.15	-	-	1.03	33.56	0.02	Sn 0.87	33	84	47	70	26
70-30 Cupronickel	DUL	HR ANN.	-	0.94	-	-	-	29.64	-	-	0.61	68.55	-	Zn 0.24	20	59	49	70	22
70-30 Cupronickel	DWS	Cast	-	1.25	-	-	0.51	30.44	-	-	0.51	66.82	-	Cb 0.47	30	60	33	43	18
Ni-Al Bronze	DYQ	Cast	-	0.66	-	-	-	5.17	-	-	3.71	80.08	10.34	-	39	93	15	17	18

Q&T - Quenched and tempered
HR ANN. - Hot rolled and annealed
Bal - Balance
ksi - Thousand pounds per square inch
YS - Yield strength
TS - Tensile strength
ELONG - Elongation
RED - Reduction

*Abbreviations used in this text are from the GPO Style Manual, 1967, unless otherwise noted.

$$S_{PE} = \frac{\Delta \epsilon_t E}{2} \qquad .....(2)$$

where

S_{PE} = reversed pseudoelastic stress, psi

E = modulus of elasticity, psi

The criterion for failure in the flexural tests was the development of one or more surface cracks 1/8 to 3/16 inch in length.

The direct stress fatigue specimen used in the NASA tests is shown in Figure 2. All of the tests were conducted in air and were of the completely reversed type (mean strain ≈ 0). The total applied diametral strain range ($\Delta \epsilon^d$) was maintained practically constant throughout the test by periodic optical strain measurements. On the basis of these measurements, the reversing microswitches which controlled the motion of die platens were readjusted to compensate for any changes caused by strain softening or strain hardening. Continuous load recordings were taken during the early part of the test and periodically thereafter. Specimen life was defined as the number of cycles (N_f) causing separation of the test section.

The total applied diametral strange range was converted to the total longitudinal strain range ($\Delta \epsilon^{\ell}$) by means of the following relationship:

$$\Delta \epsilon^{\ell} = \frac{\Delta P}{AE} (1 - 2\mu) + 2\Delta \epsilon^d$$

where

ΔP = total load range at 1/2 N_f, lb

A = cross-sectional area at minimum section, square inches

E = modulus of elasticity, psi

μ = Poisson's ratio

The total load range (ΔP) at half-life and the total longitudinal strain range were used to calculate the nominal reversed stress and reversed pseudoelastic stress as follows:

$$S_R = \frac{\Delta P}{2A} \qquad .....(4)$$

and

$$S_{PE} = \frac{\Delta \epsilon_t E}{2} \qquad .....(5)$$

RESULTS AND DISCUSSION

The results of the MEL and NASA fatigue tests are plotted and compared in Figures 3 through 8. The upper curves in each graph show the relationship between nominal reversed stresses, S_R (Equations (1) and (4)), and number of cycles to failure. The lower curves show the reversed pseudoelastic stress, S_{PE} (Equations (2) and (5)), relationships. Except for the HY-100 steel, the correlation between flexure and direct stress results based on S_{PE} is exceedingly good, and perhaps even fortuitous, considering the differences in test procedures and failure criteria. Examination of the specimen fractures and related test data did not reveal any assignable cause for the differences observed in HY-100 steel. Noteworthy, however, is the fact that the flexure results in this case are the more conservative of the two.

Correlations based on S_R generally showed distinct differences in behavior. The reason for this becomes apparent when the cyclic stress-strain relationships, such as shown in Figure 9, are considered. It has been demonstrated by MEL and others that total strain range is a controlling factor in determining the low-cycle fatigue life of a material. Accordingly, for a given fatigue life (total strain range) the required flexural stress will be higher than the required direct stress when linear elastic stress conditions are exceeded.

CONCLUSIONS

It is concluded that the flexural fatigue tests as performed by MEL and the direct stress fatigue tests as performed by NASA will give equivalent results within the life range investigated when correlated on a total strain-range (pseudoelastic stress) basis. Correlations based on nominal stress are not as good because of differences between the cyclic stress-strain relationships for the two types of tests.

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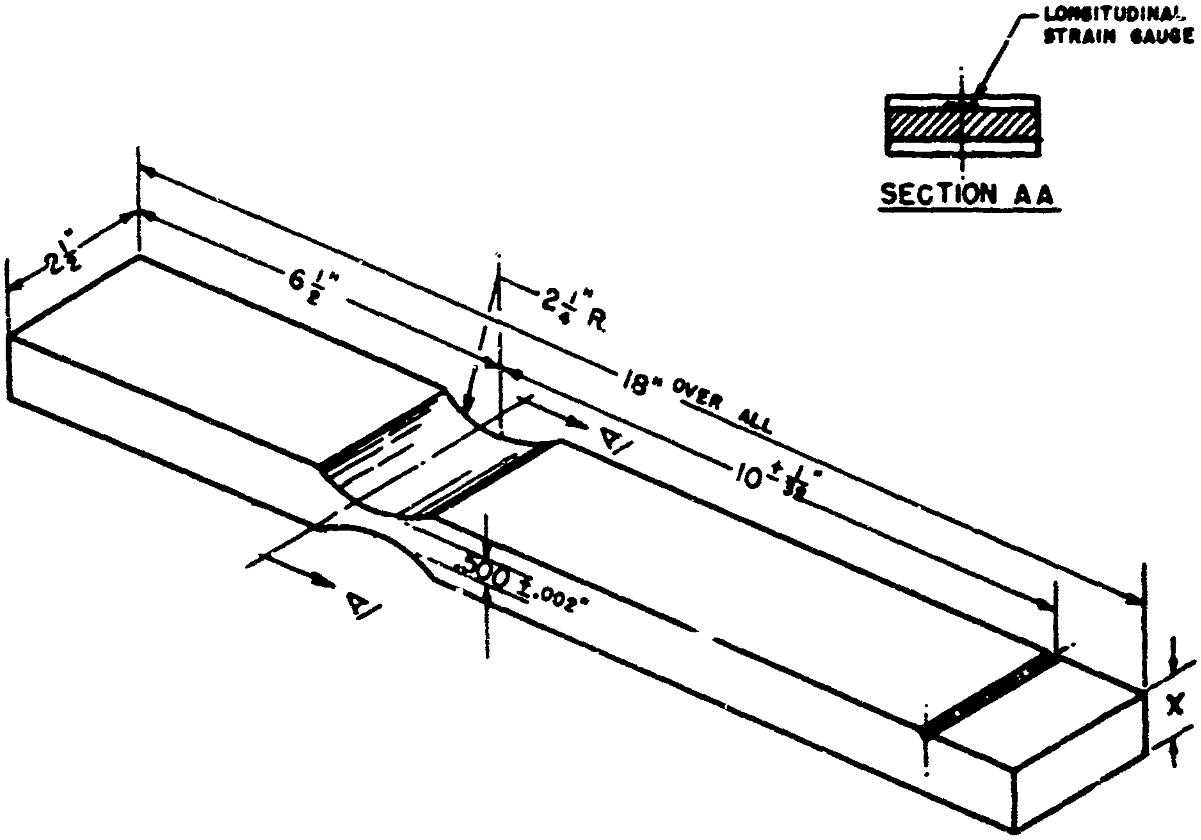
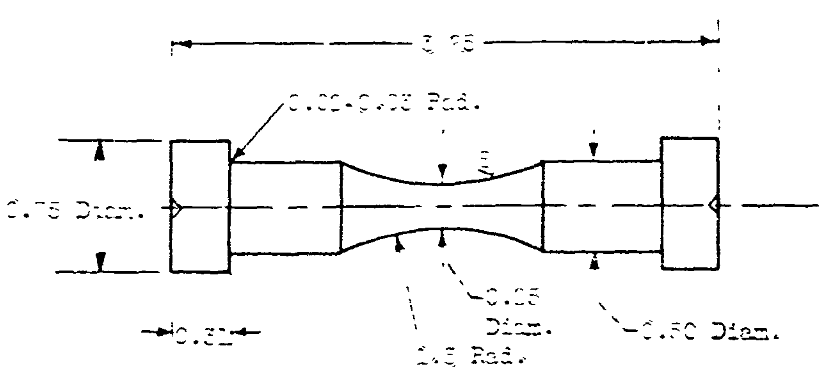


Figure 1 - MEL Flexural Fatigue Specimen



NASA Drawing

Figure 2 - NASA Direct Stress Fatigue Specimen

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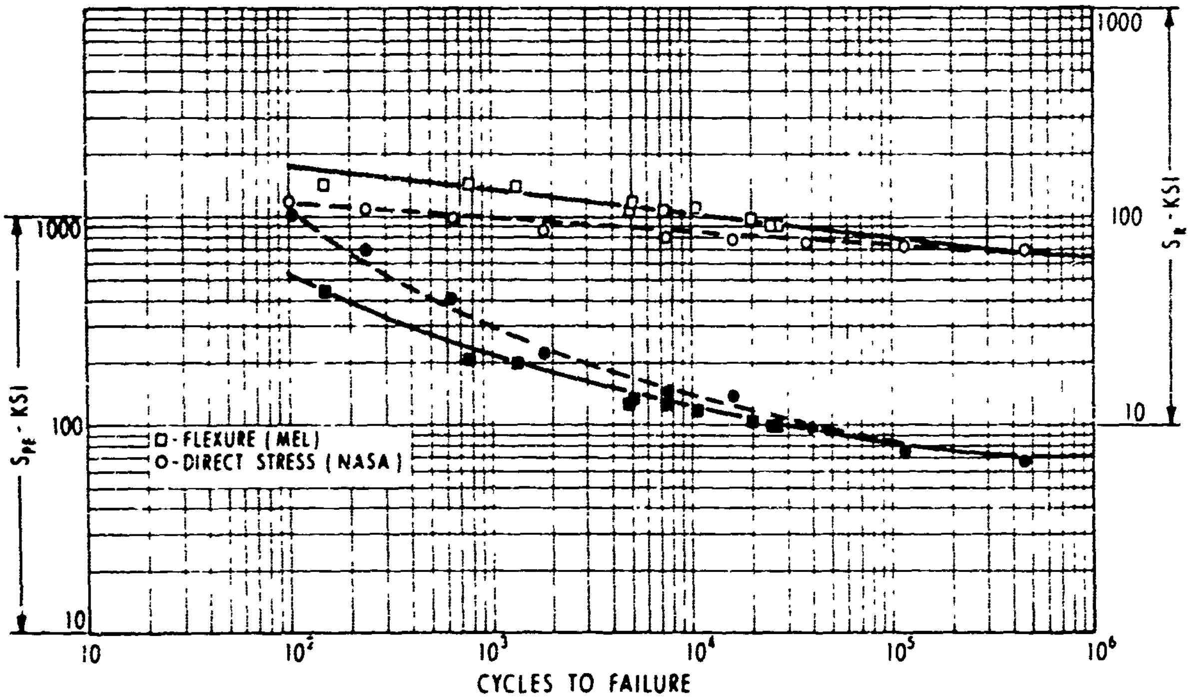

Figure 3 - Fatigue Results for HY-100 Steel

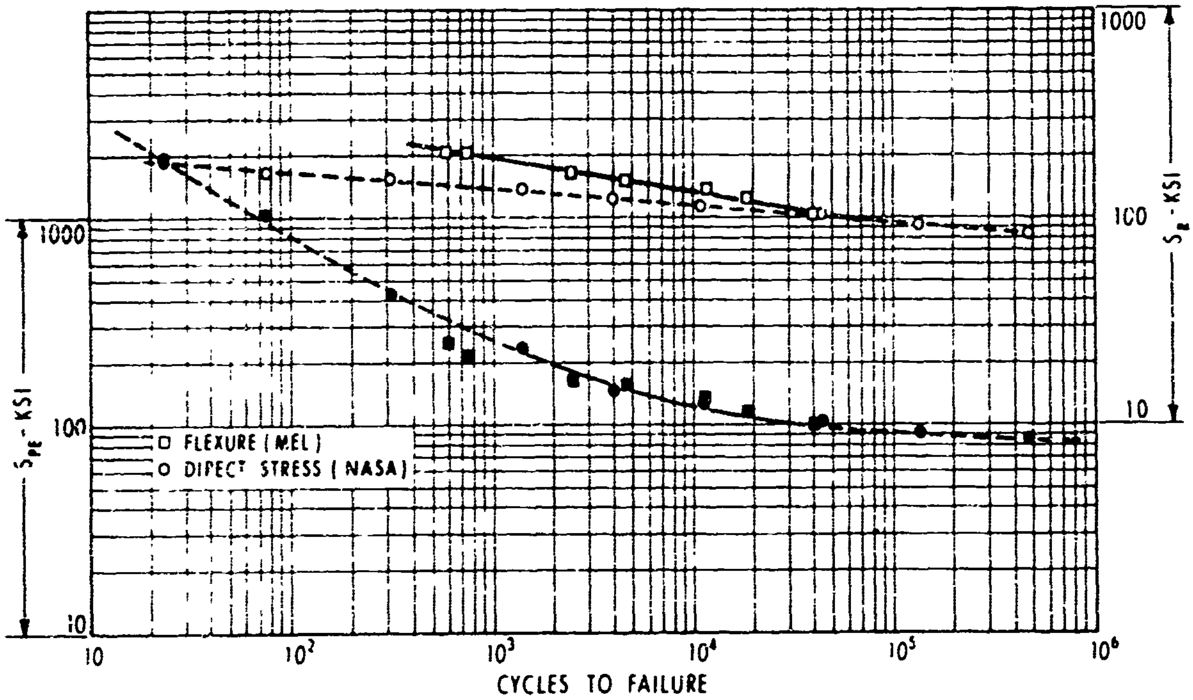

Figure 4 - Fatigue Results for HY-140 Steel

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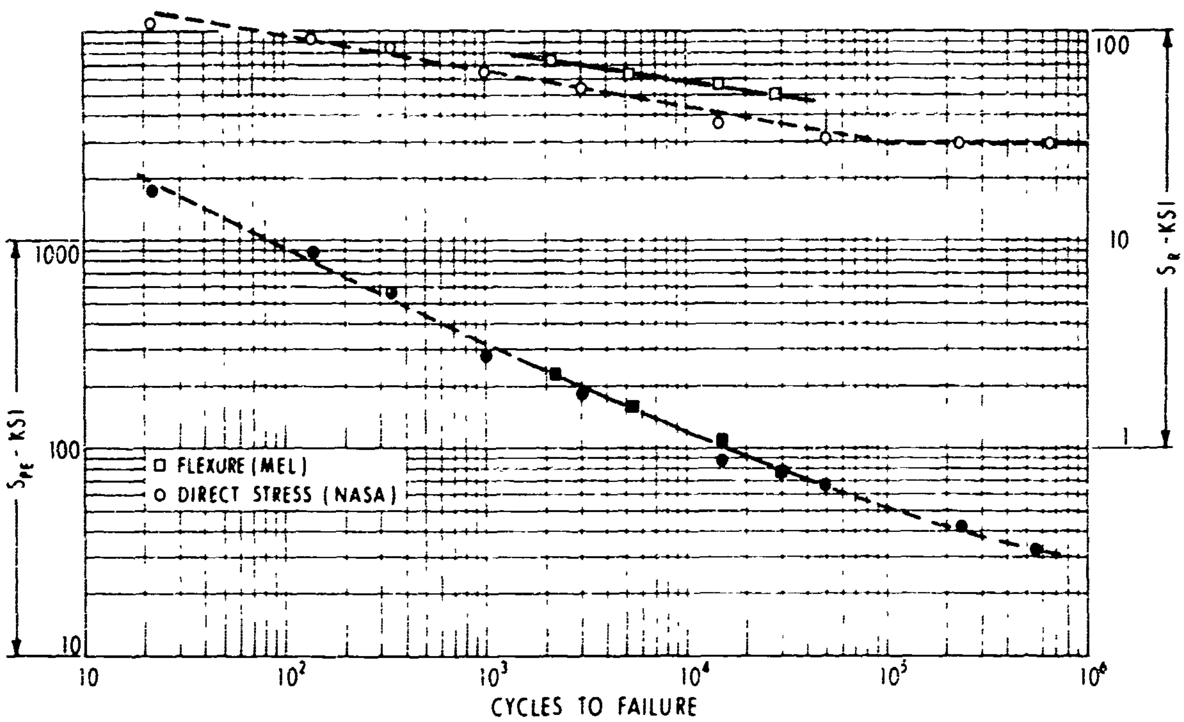

Figure 5 - Fatigue Results for Monel-400

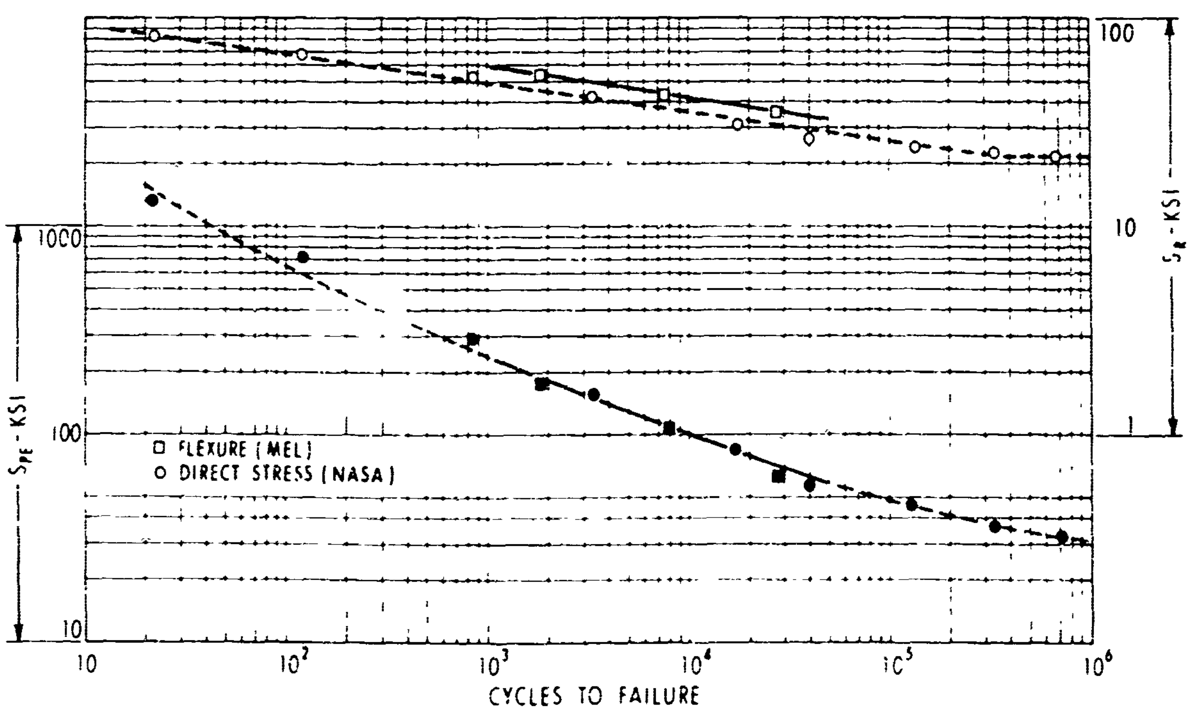

Figure 6 - Fatigue Results for Wrought 70-30 Cupronickel

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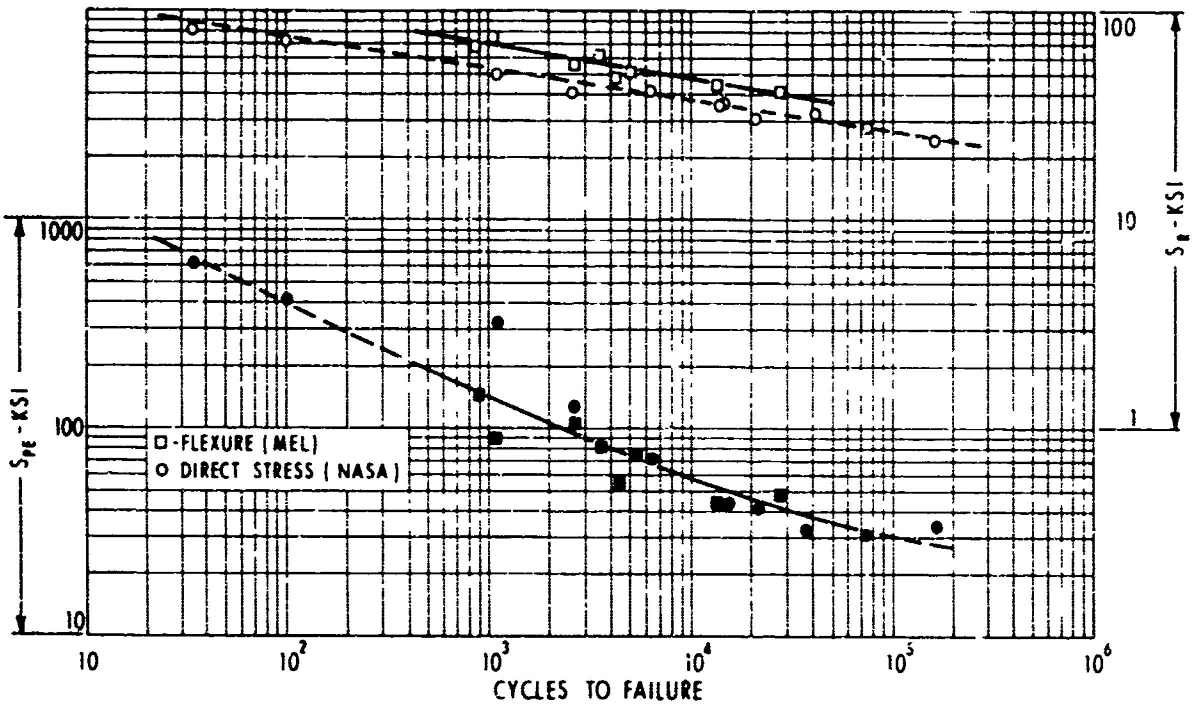

Figure 7 - Fatigue Results for Cast 70-30 Cupronickel

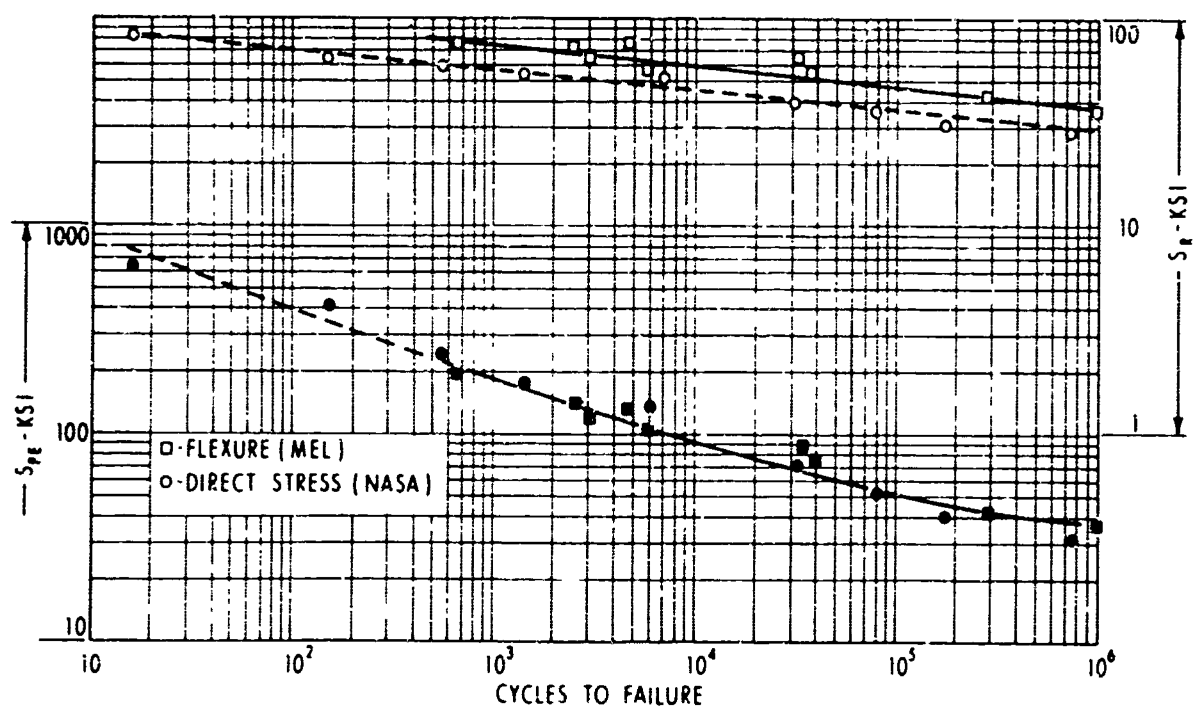

Figure 8 - Fatigue Results for Cast Ni-Al Bronze

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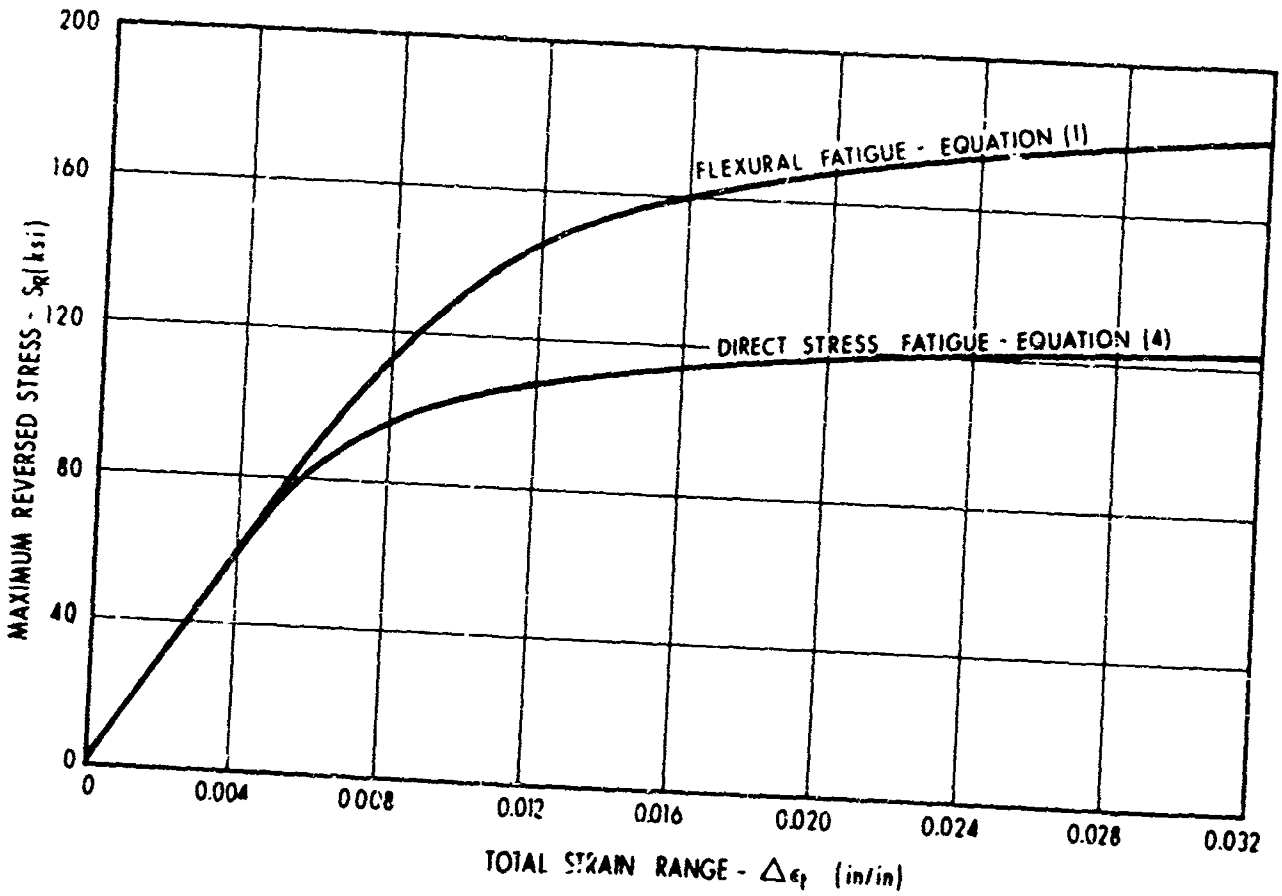

Figure 9

Cyclic Stress-Strain Relationships for HY-100 Steel

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